Cryogenic High Accuracy Refractive Measuring System (CHARMS): Recap of Recent Work

Kevin H. Miller (GSFC Optics Branch)

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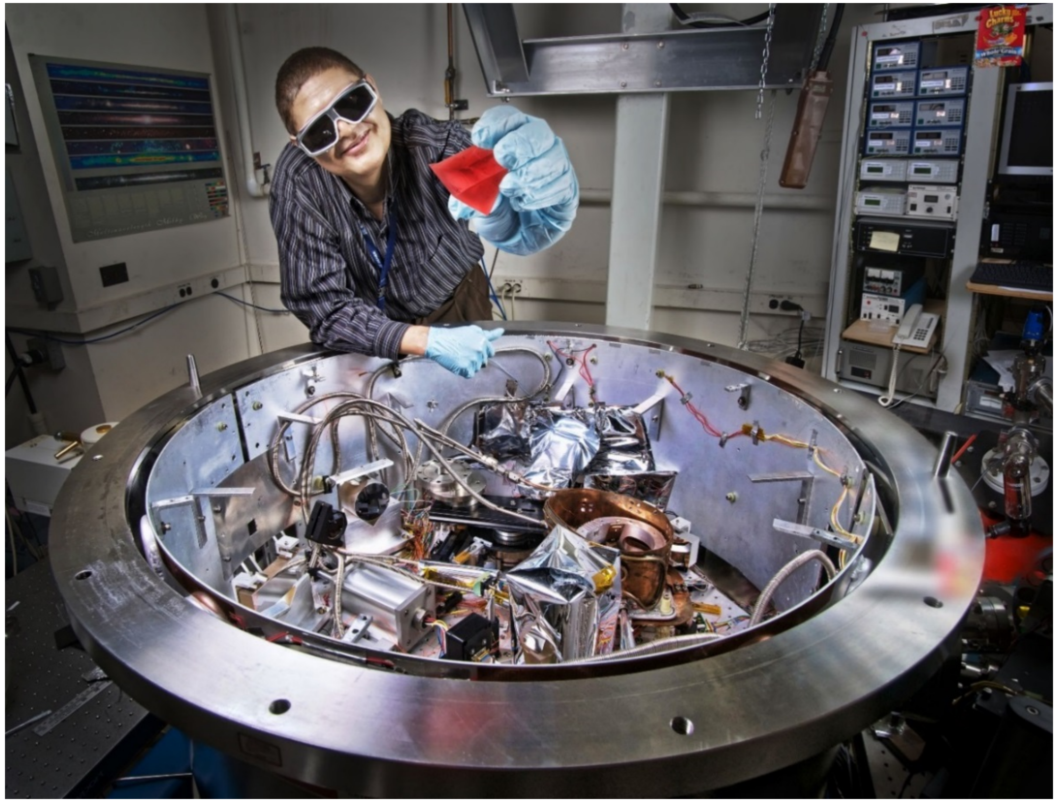
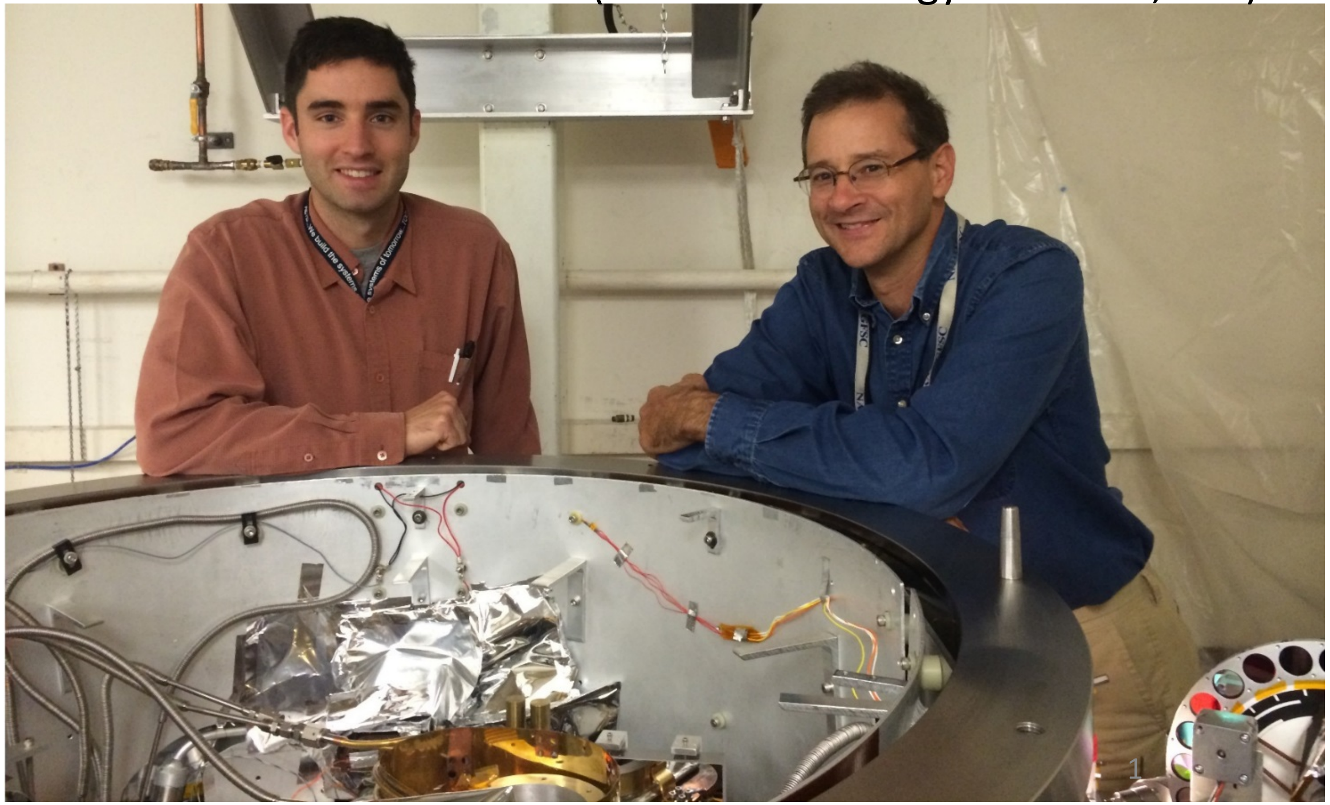
Manuel A. Quijada (GSFC Optics Branch)

Douglas B. Leviton
(Leviton Metrology Solutions, Inc.)





CHARMS Capabilities

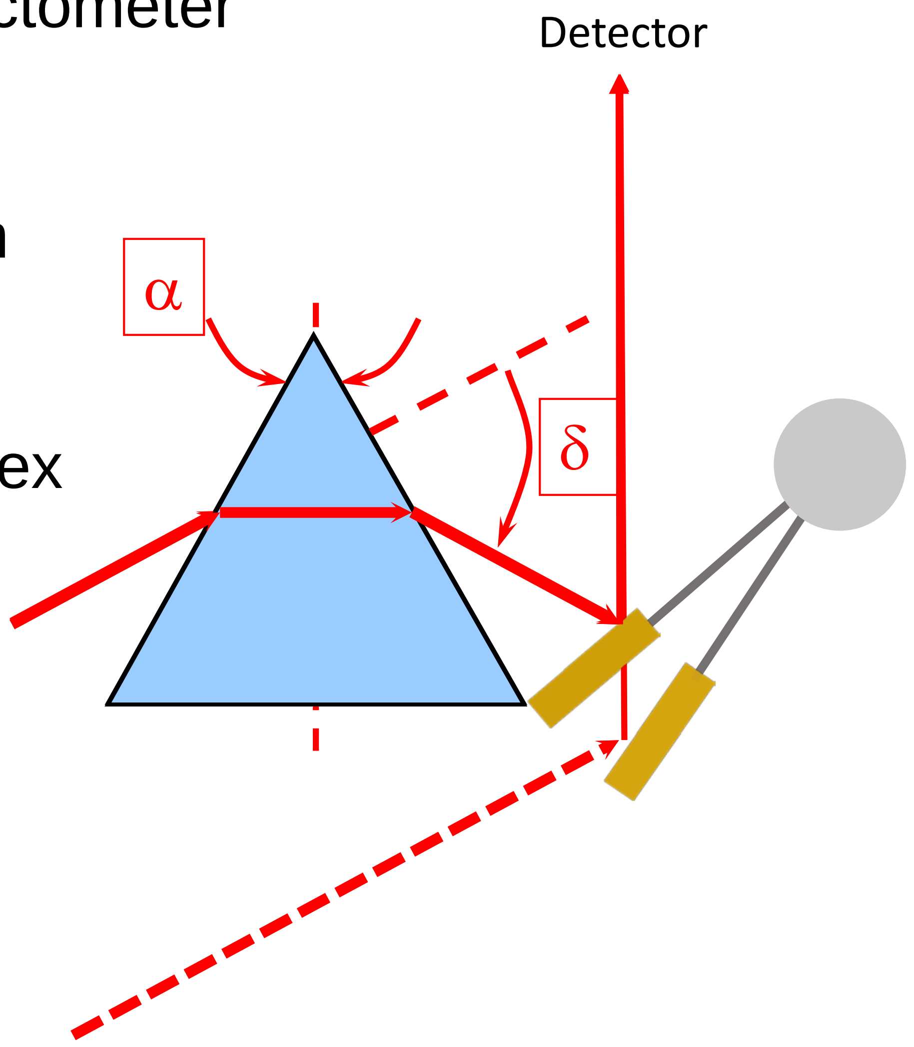
- Absolute minimum deviation refractometer (in vacuum)
- Wavelength coverage: 0.35 to 5.6 μm
- Temperature coverage: 15 K (using LHe) to 340^{+} K (67 C)
- Single measurement ABSOLUTE accuracies as good as 5×10^{-6} at cryo (depending on material)
- Measures absolute refractive index, $n(\lambda, T)$
- Accurate values of thermo-optic coefficient, dn/dT, and spectral dispersion, $dn/d\lambda$, derived from measured $n(T)$

CHARMS: Operation and Capabilities

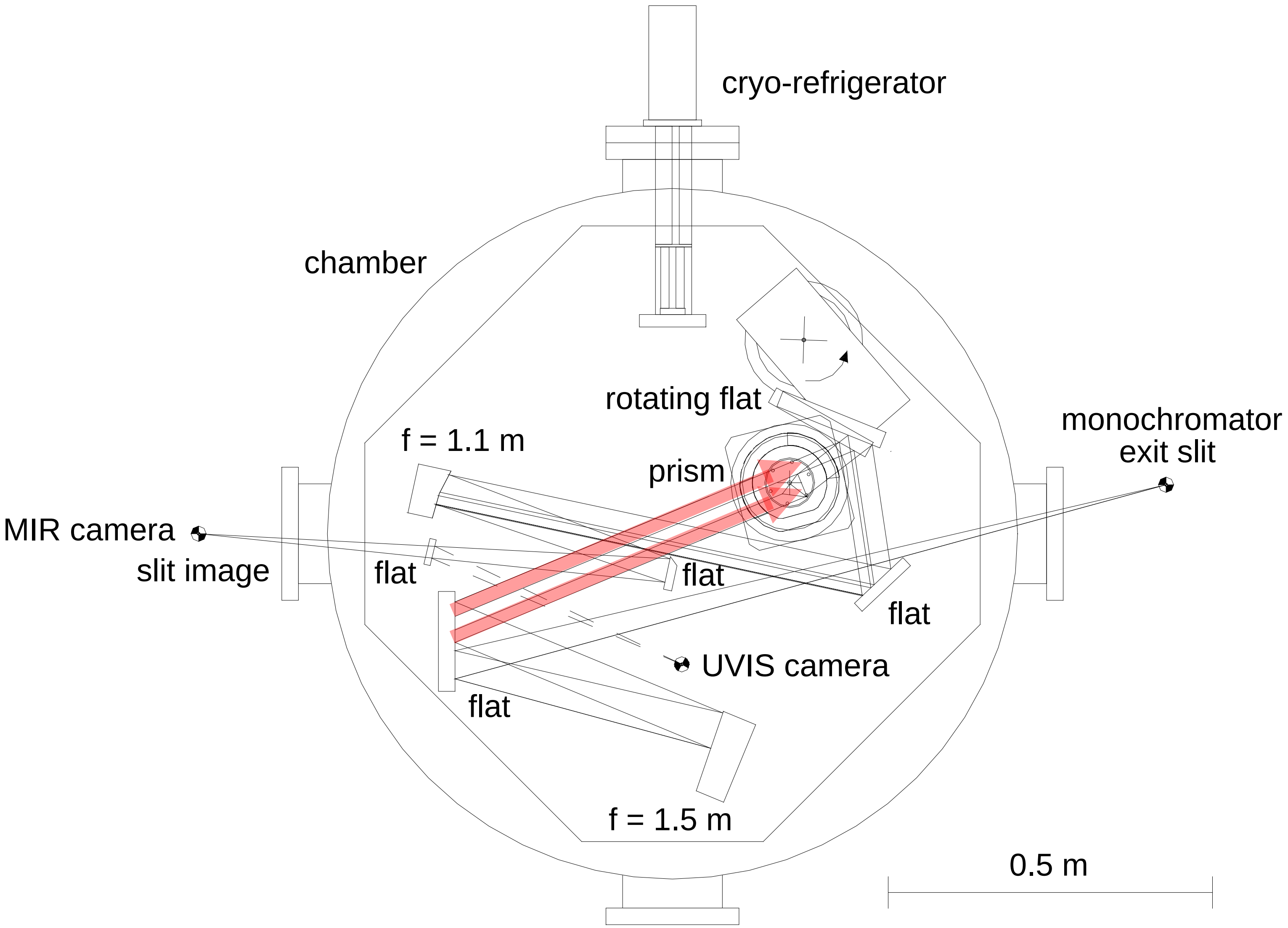
- CHARMS is a minimum deviation refractometer
- Five simple steps:

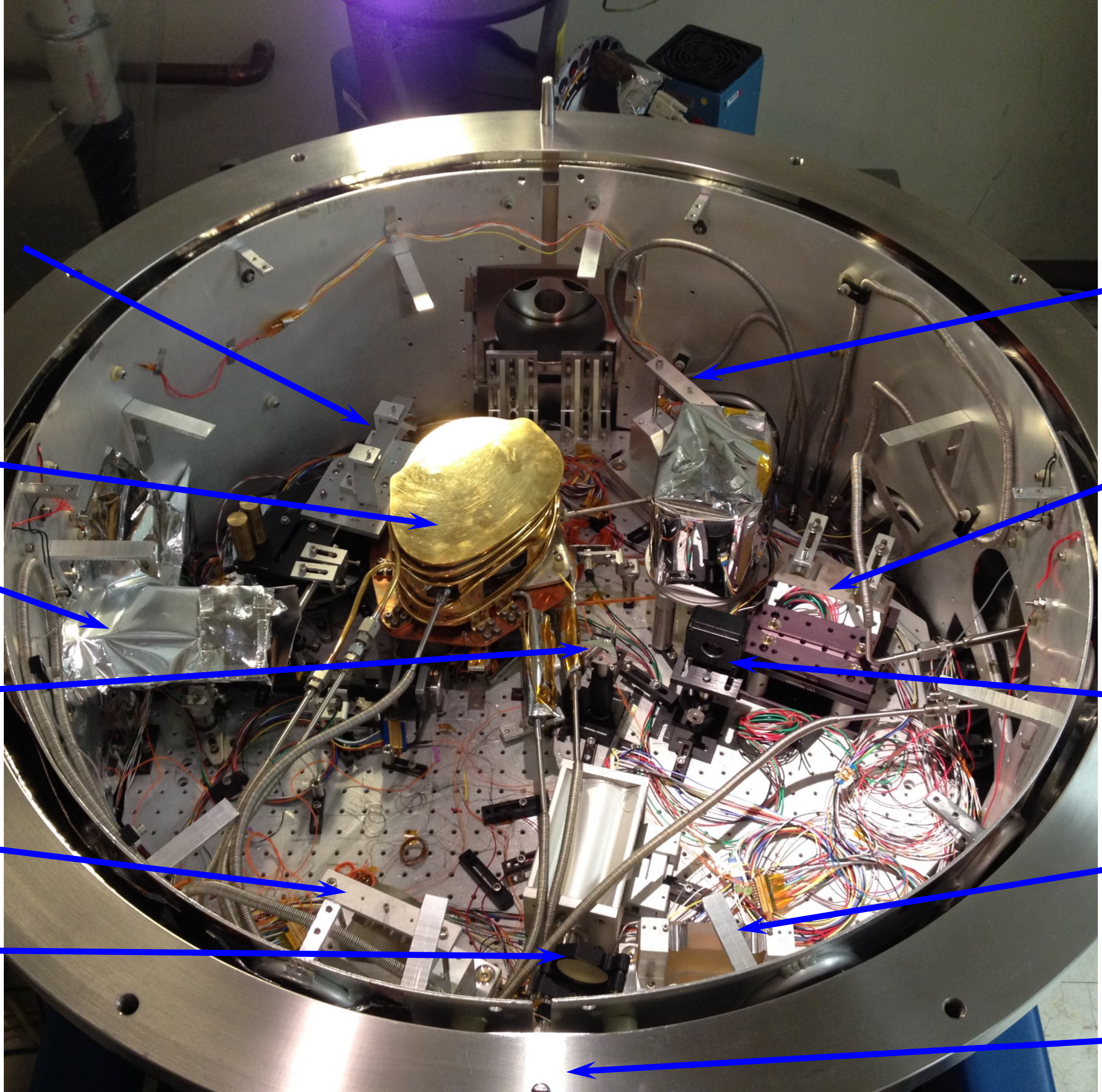
1. Measure the apex angle of the prism
2. Establish the condition of min deviation
3. Measure angle of undeviated beam
4. Measure angle of deviated beam
5. Compute deviation angle; compute index

$$n = \frac{\sin\left(\frac{\alpha+\delta}{2}\right)}{\sin\left(\frac{\alpha}{2}\right)}$$

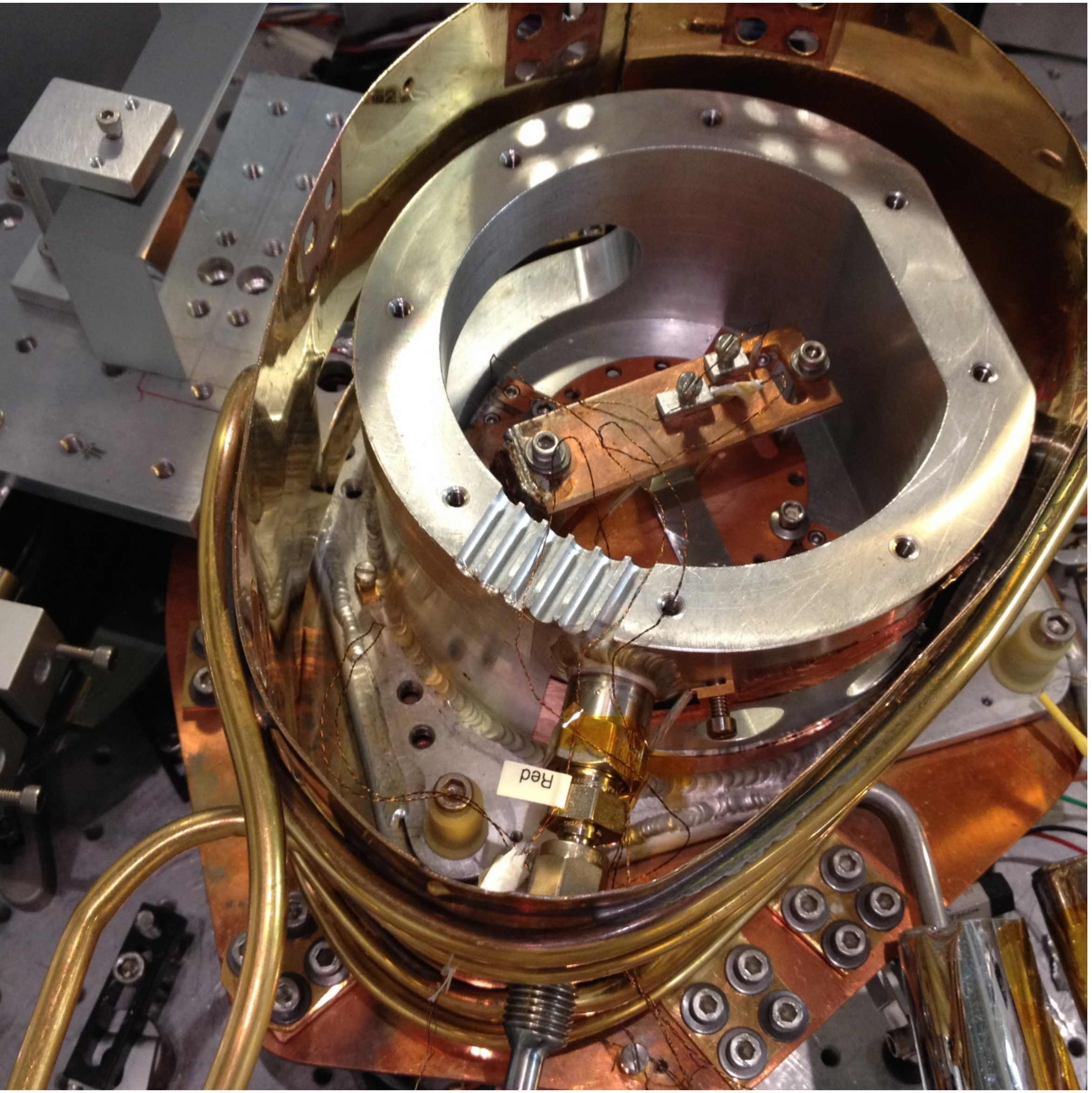


CHARMS optical layout

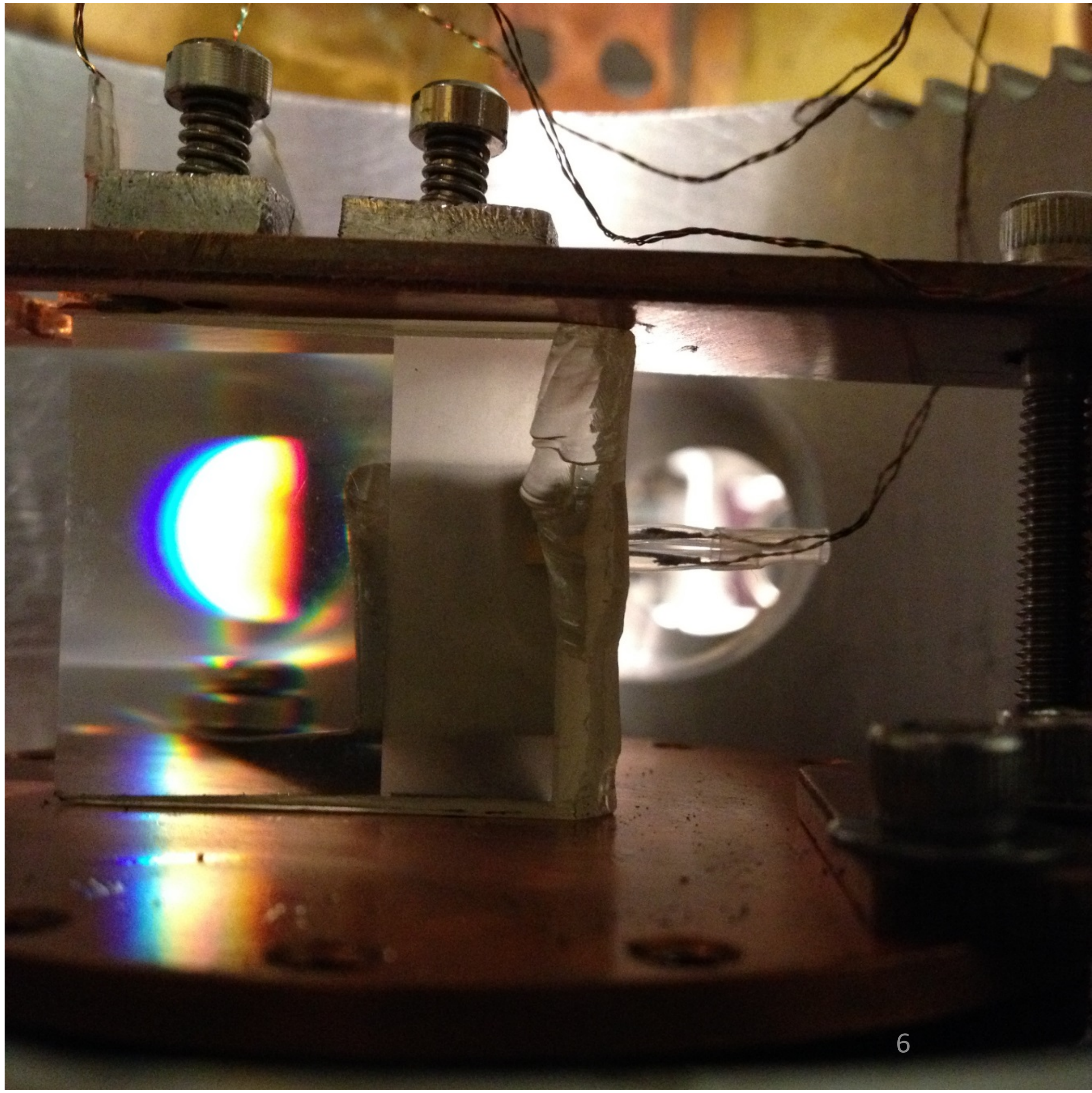



rotating fold flat
sample chamber
“shield”
cryo refrigerator
“focus” flat
camera mirror
detector
select mirror
fixed fold flat
collimator
UVIS
camera
collimator fold flat
MIR camera (not shown)

Top view of sample chamber

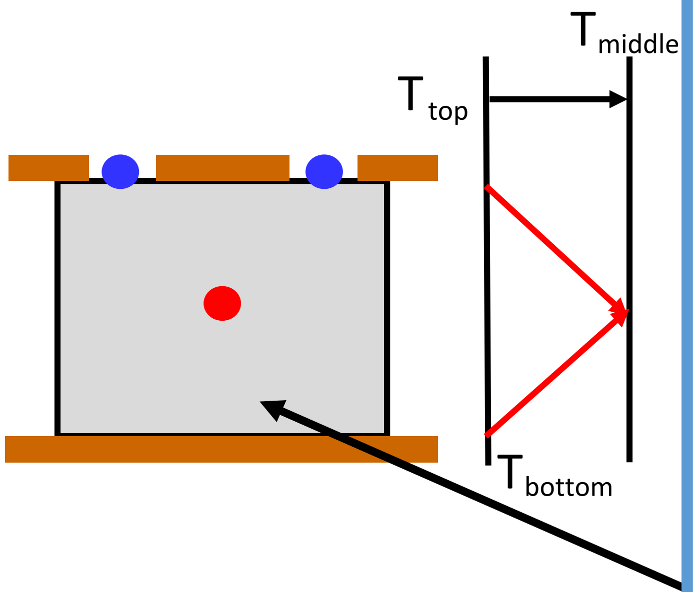


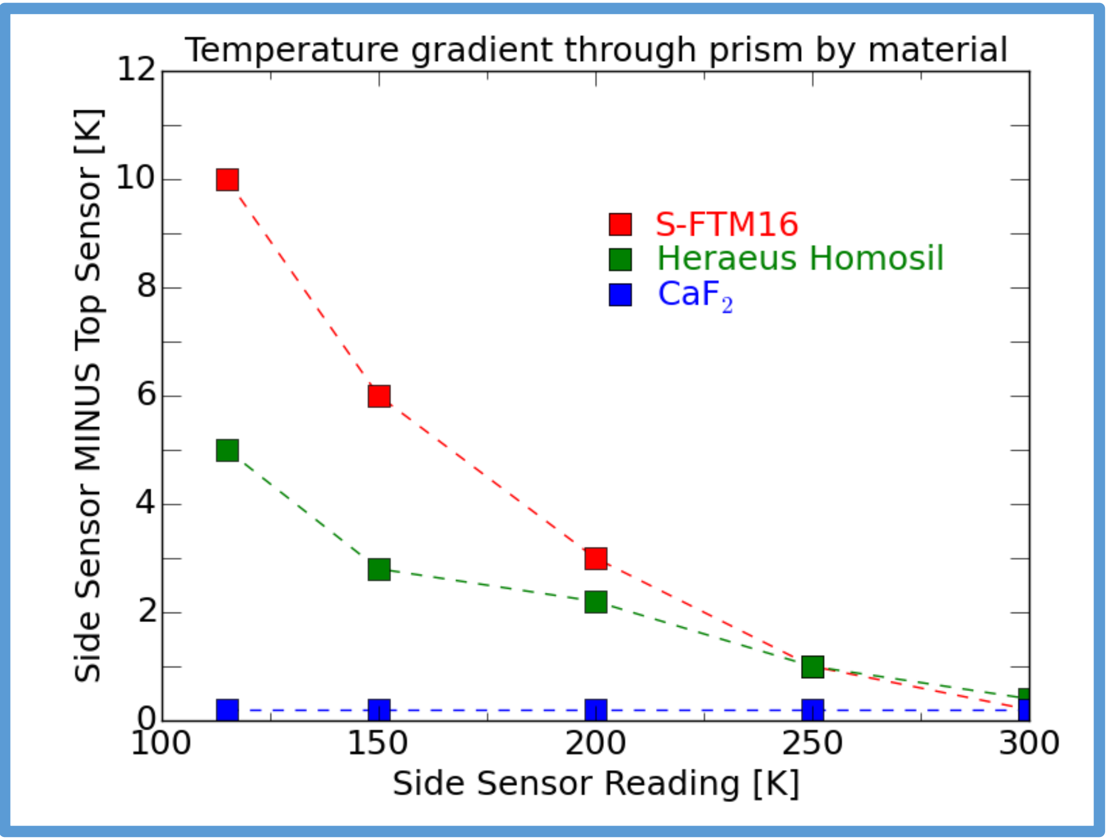
Eye level with prism

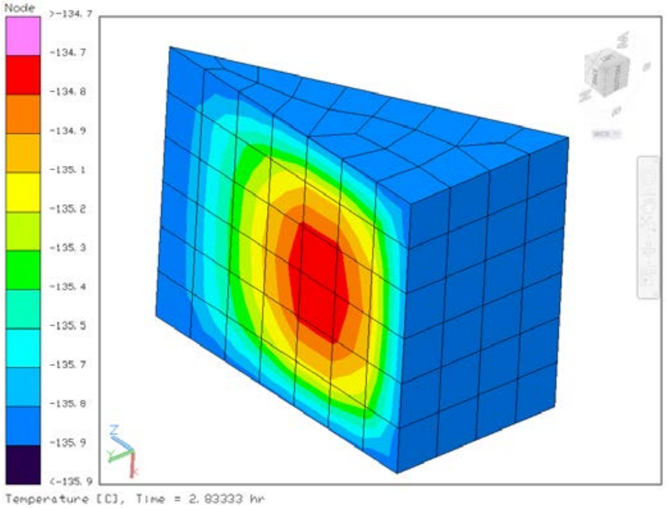


Sample Temperature, T

- sample sandwiched between two cryogen-cooled copper plates at essentially same T
- two T sensors on top of prism
- T_{sample} attributed to reading from sensor halfway up side of non-refracting face





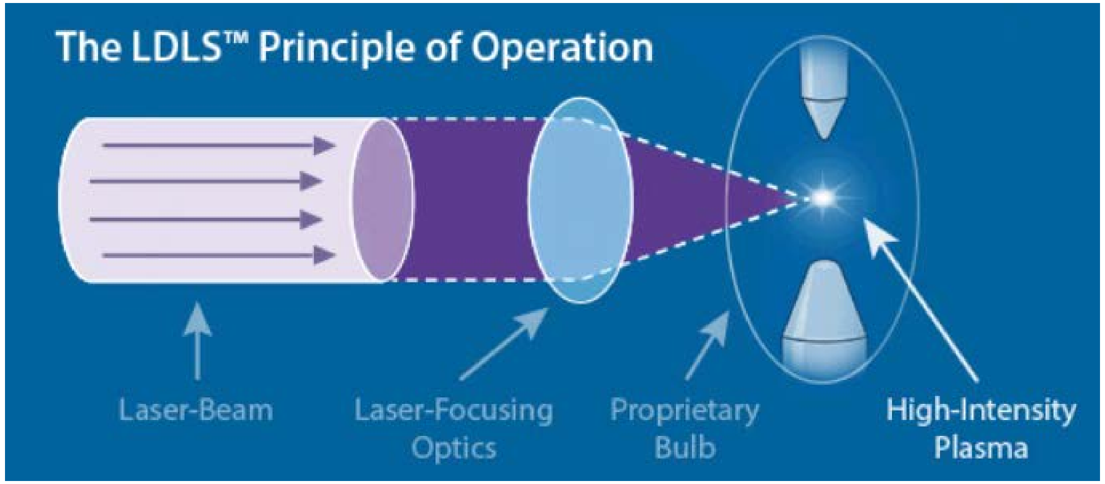


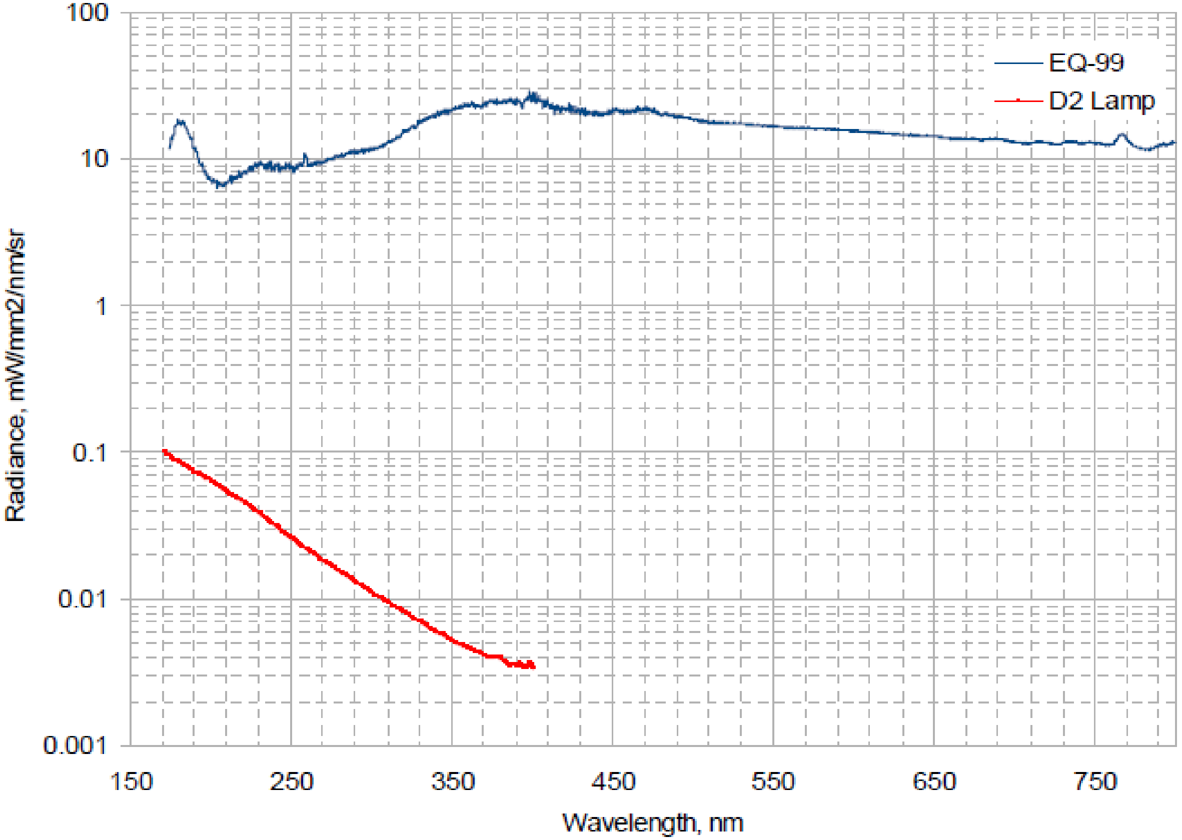
Courtesy of S. Scola – NASA LaRC

Laser Driven Plasma Light Source

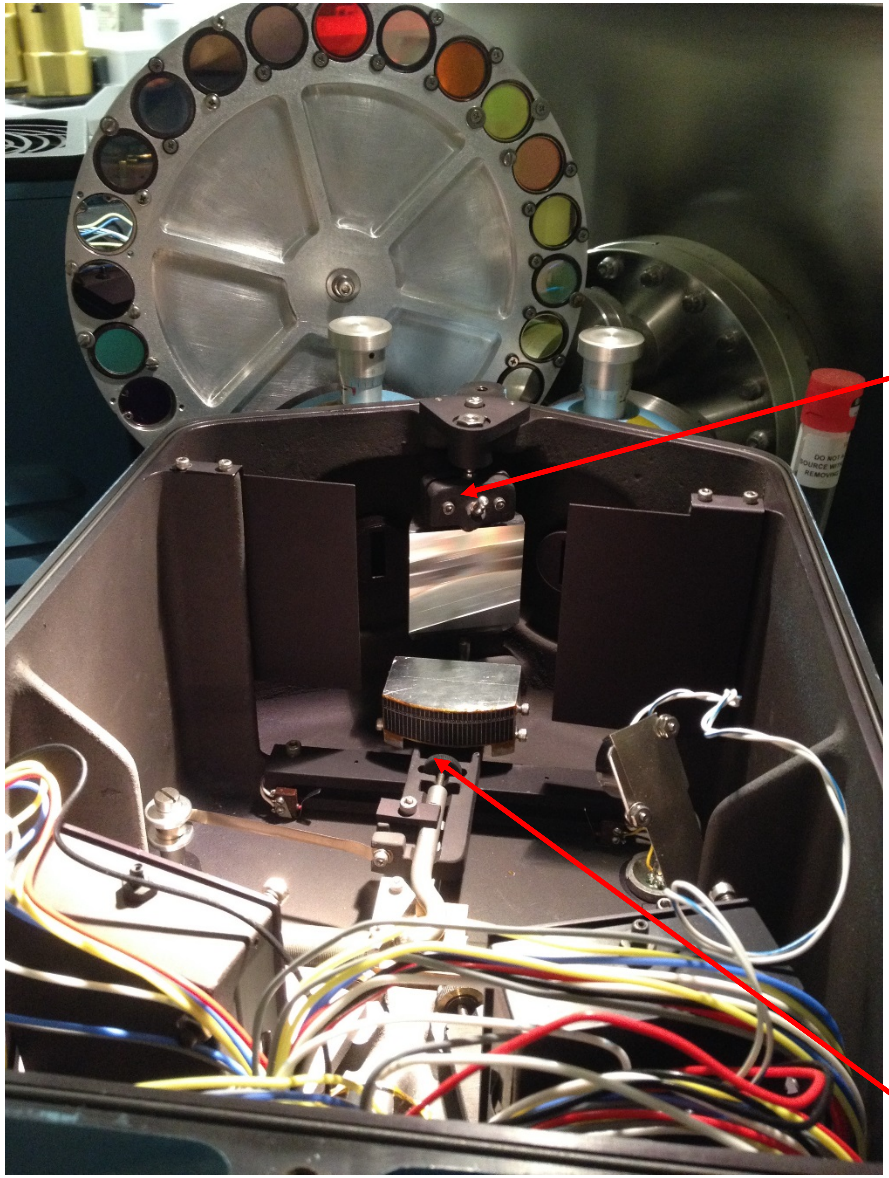
Energetiq 99

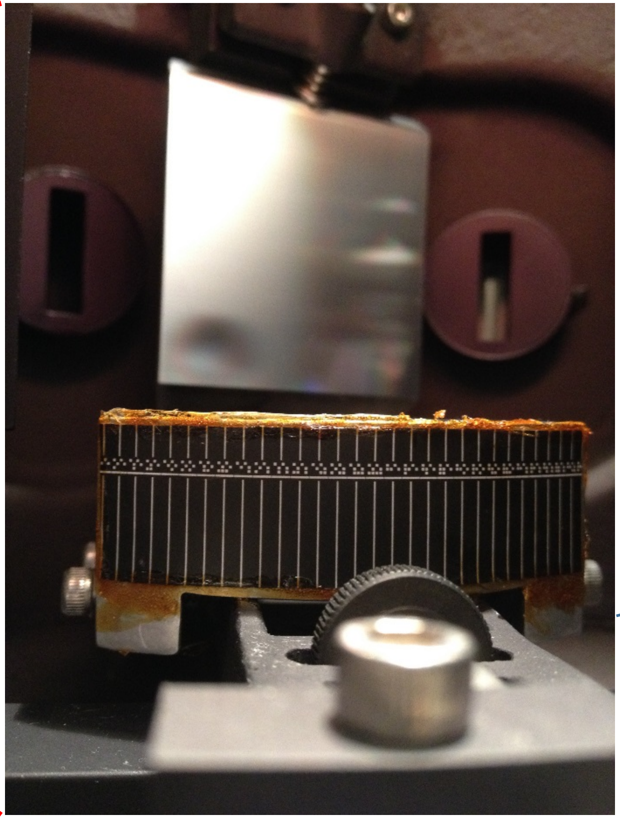
- CW laser heats Xenon plasma
- Electrodeless
- 100 micron plasma size

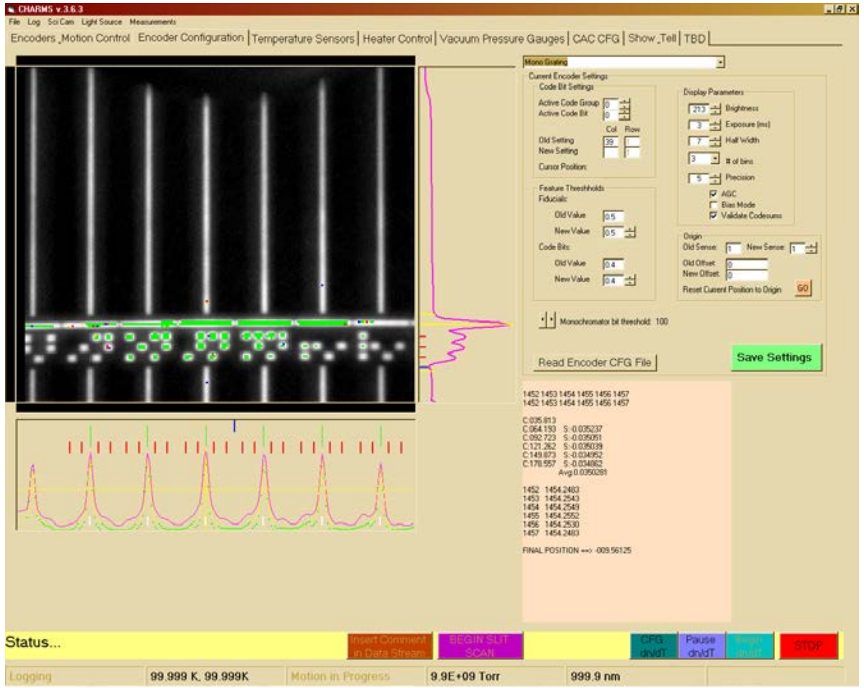




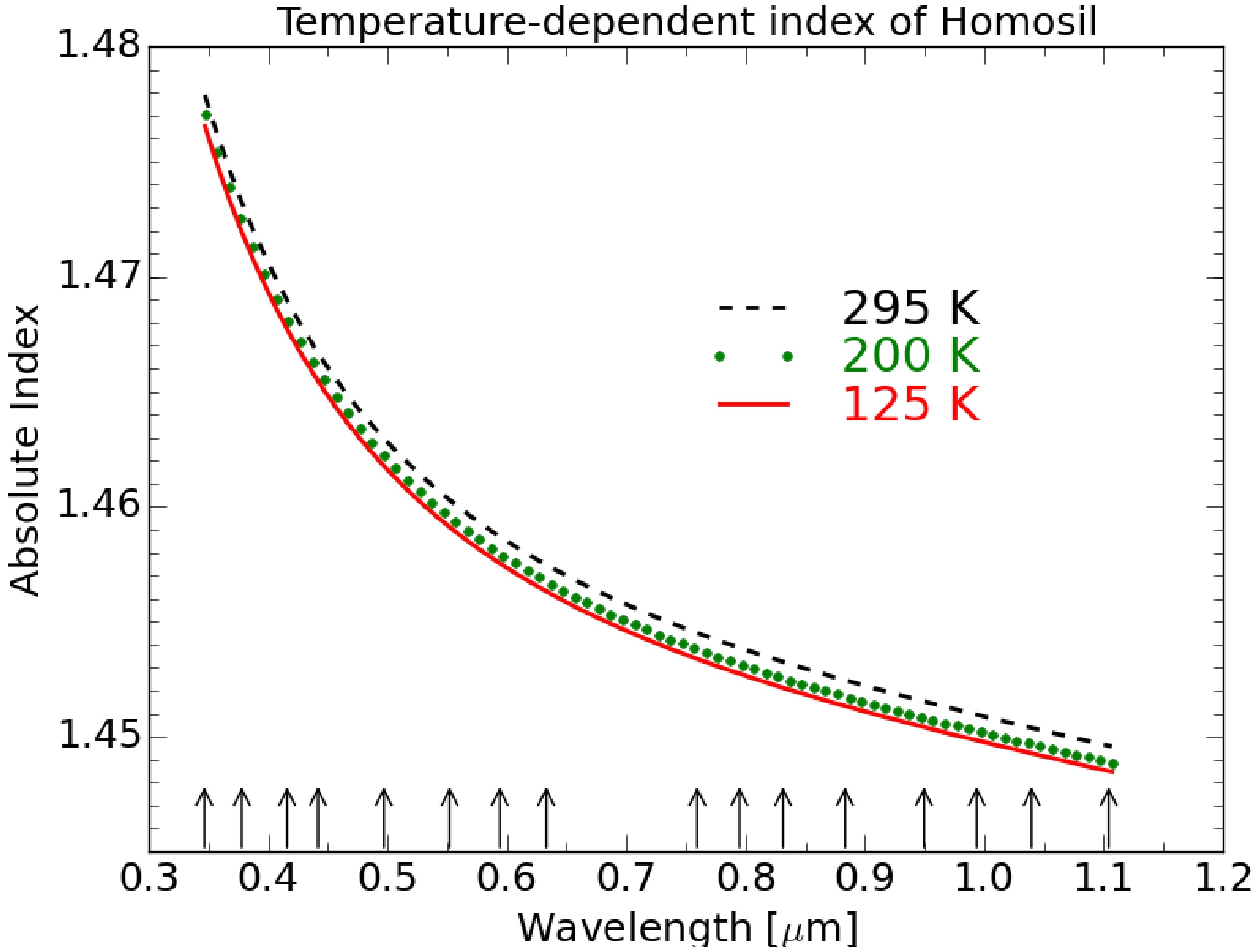
Wavelength Calibration & Encoder Technology







CHARMS Measurements of Heraeus Homosil



Sellmeier Equation

$$n^2(\lambda, T) - 1 = \sum_{i=1}^{3} \frac{S_i(T) \cdot \lambda^2}{\lambda^2 - \lambda_i^2(T)}$$

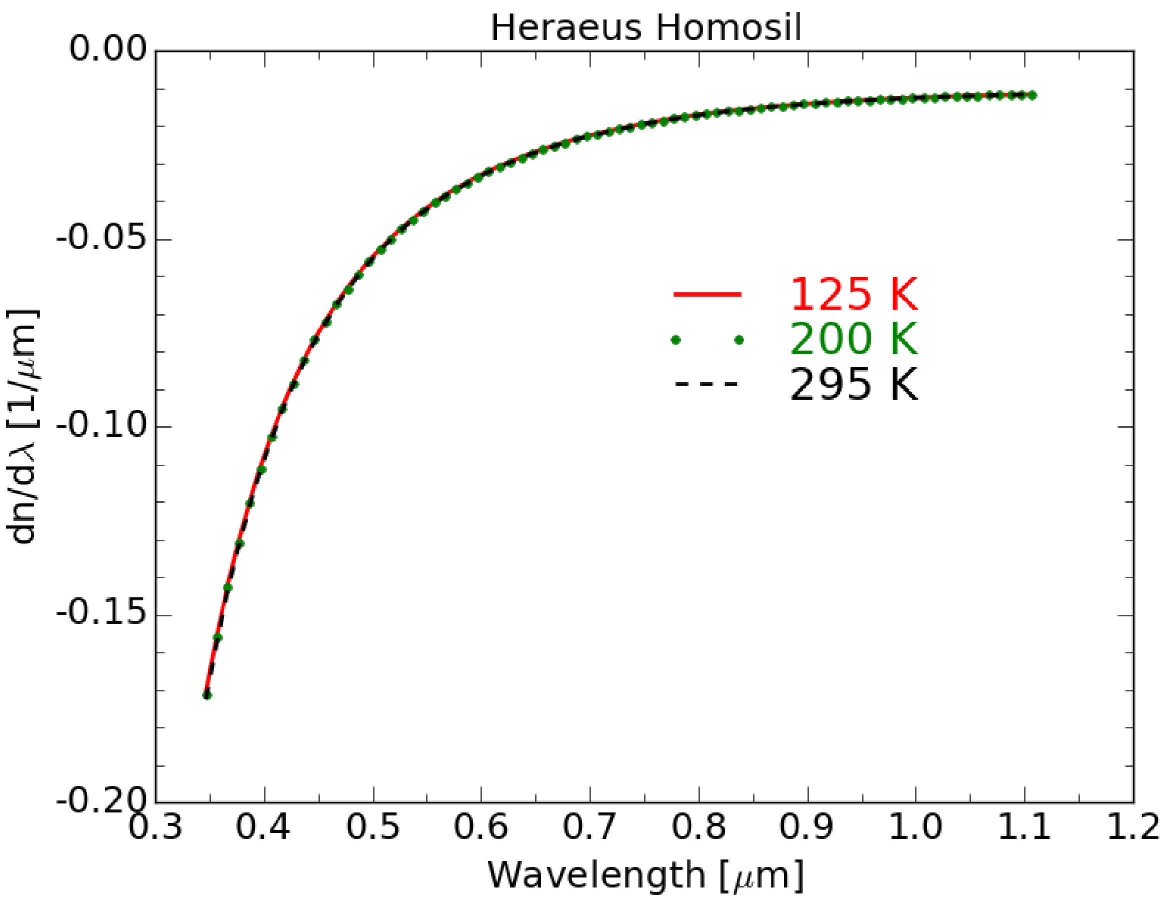
$$S_i(T) = \sum_{j=0}^{3} S_{ij} \cdot T^j$$

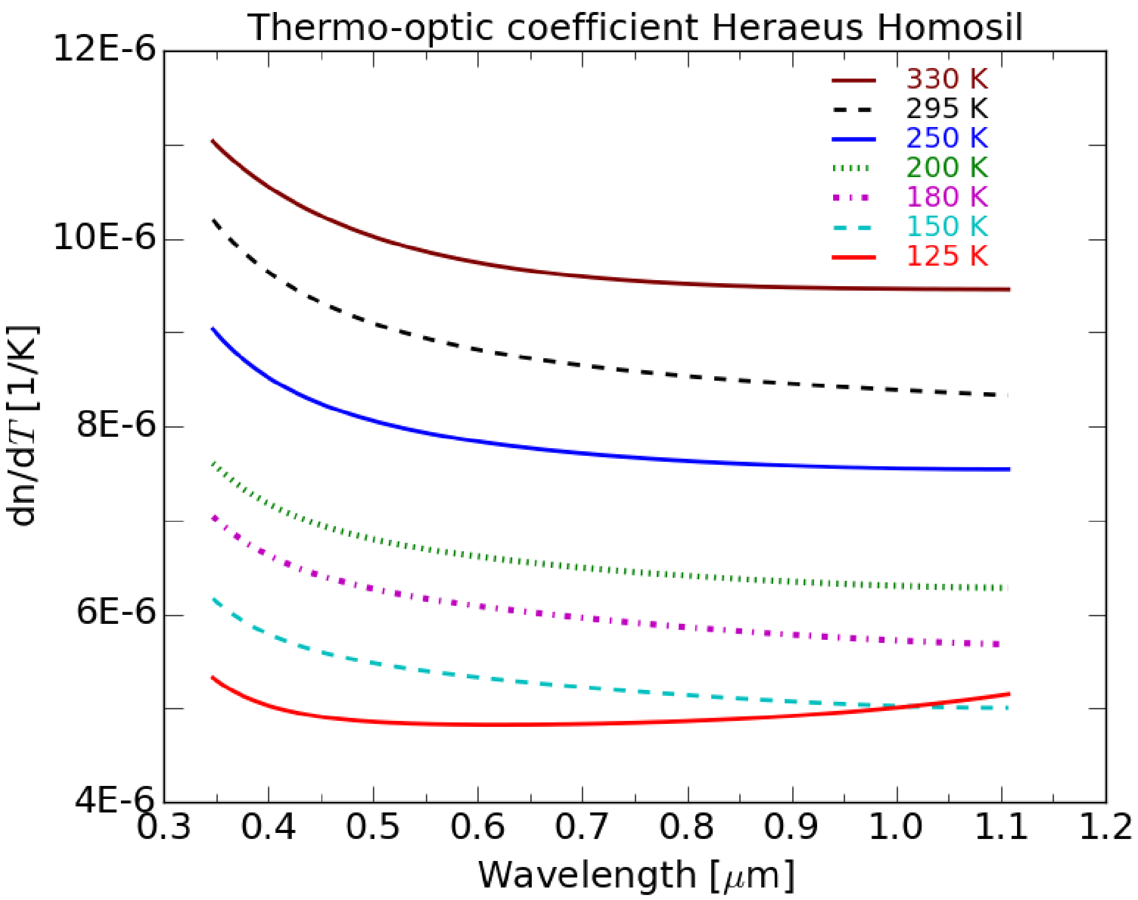
$$\lambda_i(T) = \sum_{j=0}^{3} \lambda_{ij} \cdot T^j$$

$$AAR = \frac{\sum_{k=1}^{n} |index_{measured} - index_{fit}|}{n}$$

Homosil_AAR = 2.04 x 10^{-6}

Derived Properties of Heraeus Homosil





Example of Bookkeeping Error Budget

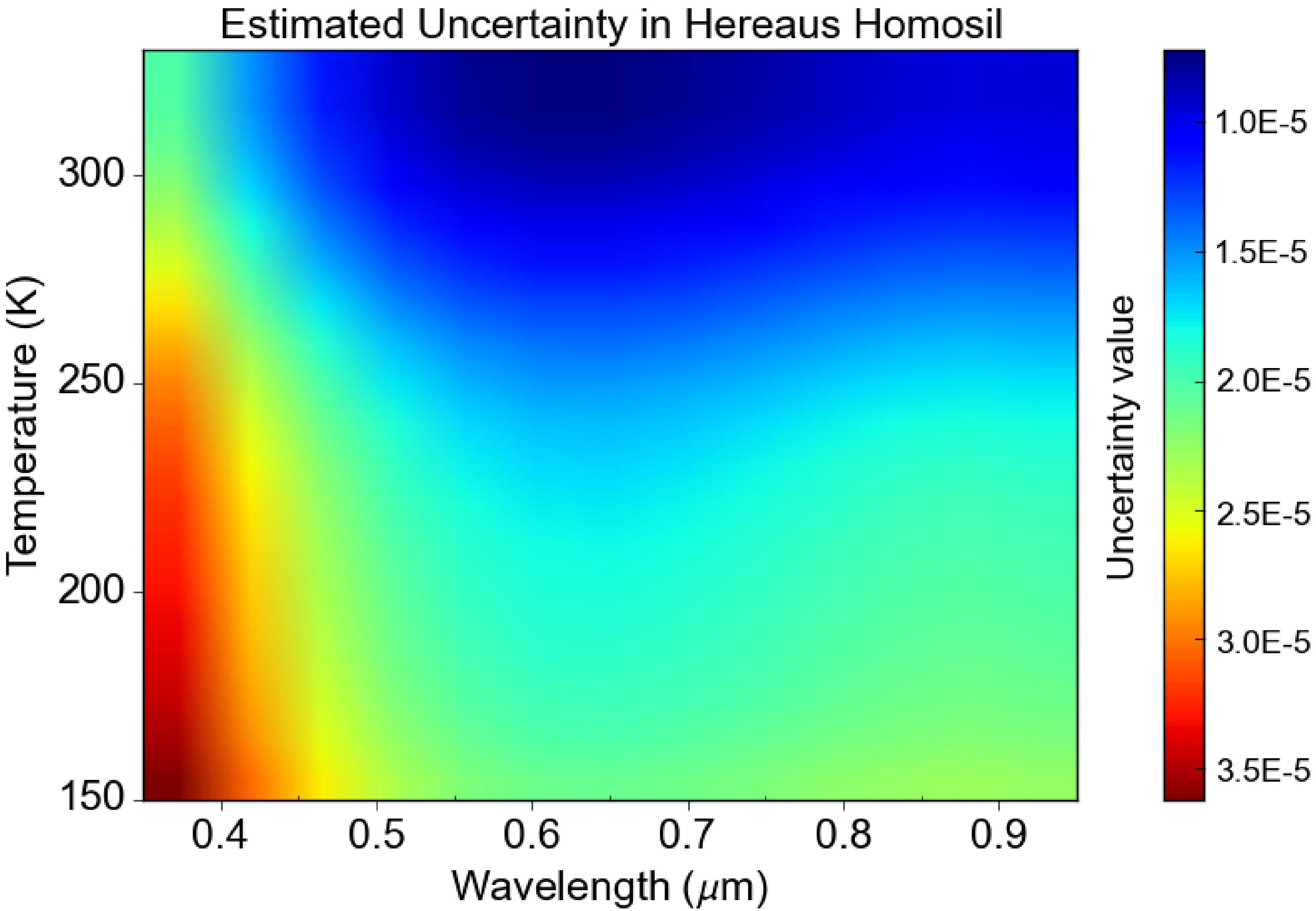
index n apex α deviation δ $dn/d\lambda$ dn/dT $dn/d\alpha$ $dn/d\delta$ $d\lambda$ dT da $d\delta$ $\rightarrow$ **dn**

					SENSITIVITIES								FOR SPECIFIED PRISM				FOR SPECIFIED PRISM				
index n	apex a	alpha	delta d		dn/dwv	dn/dT	dn/da	dn/d	dwv	dn(dwv)	dT	dn(dT)	da			dn(da)	dd			dn(dd)	dn r.s.s.
1.4574	10.0 deg	0.175 rads	4.595 deg	0.080 rads	0.00040/nm	0.000120/K	-2.64/rad	5.690/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-6.4E-06	0.00150 deg	5.4 sec	###	1.5E-04	1.7E-04
1.4574	20	0.349 rads	9.319 deg	0.163 rads	0.00040/nm	0.000120/K	-1.35/rad	2.786/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.3E-06	0.00150 deg	5.4 sec	###	7.3E-05	9.5E-05
1.4574	30	0.524 rads	14.321 deg	0.250 rads	0.00040/nm	0.000120/K	-0.93/rad	1.789/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.3E-06	0.00150 deg	5.4 sec	###	4.7E-05	7.4E-05
1.4574	40	0.698 rads	19.796 deg	0.346 rads	0.00040/nm	0.000120/K	-0.73/rad	1.267/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.8E-06	0.00150 deg	5.4 sec	###	3.3E-05	6.4E-05
1.4574	50	0.873 rads	26.038 deg	0.454 rads	0.00040/nm	0.000120/K	-0.63/rad	0.932/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.5E-06	0.00150 deg	5.4 sec	###	2.4E-05	5.9E-05
1.4574	58	1.012 rads	31.912 deg	0.557 rads	0.00040/nm	0.000120/K	-0.58/rad	0.730/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.4E-06	0.00150 deg	5.4 sec	###	1.9E-05	5.6E-05
2.6	10	0.175 rads	16.195 deg	0.283 rads	0.00040/nm	0.000120/K	-9.27/rad	5.588/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.3E-05	0.00150 deg	5.4 sec	###	1.5E-04	1.7E-04
2.6	15	0.262 rads	24.677 deg	0.431 rads	0.00040/nm	0.000120/K	-6.27/rad	3.603/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.5E-05	0.00150 deg	5.4 sec	###	9.4E-05	1.2E-04
2.6	20	0.349 rads	33.678 deg	0.588 rads	0.00040/nm	0.000120/K	-4.80/rad	2.569/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.2E-05	0.00150 deg	5.4 sec	###	6.7E-05	9.1E-05
2.6	25	0.436 rads	43.491 deg	0.759 rads	0.00040/nm	0.000120/K	-3.95/rad	1.910/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-9.7E-06	0.00150 deg	5.4 sec	###	5.0E-05	7.7E-05
2.6	30	0.524 rads	54.587 deg	0.953 rads	0.00040/nm	0.000120/K	-3.42/rad	1.429/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-8.4E-06	0.00150 deg	5.4 sec	###	3.7E-05	6.7E-05
3.4	10	0.175 rads	24.475 deg	0.427 rads	0.00040/nm	0.000120/K	-13.95/rad	5.479/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.4E-05	0.00150 deg	5.4 sec	###	1.4E-04	1.6E-04
3.4	14	0.244 rads	34.958 deg	0.610 rads	0.00040/nm	0.000120/K	-10.11/rad	3.734/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.5E-05	0.00150 deg	5.4 sec	###	9.8E-05	1.2E-04
3.4	18	0.314 rads	46.265 deg	0.807 rads	0.00040/nm	0.000120/K	-8.03/rad	2.707/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.0E-05	0.00150 deg	5.4 sec	###	7.1E-05	9.6E-05
3.4	22	0.384 rads	58.895 deg	1.028 rads	0.00040/nm	0.000120/K	-6.75/rad	1.994/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-1.6E-05	0.00150 deg	5.4 sec	###	5.2E-05	8.0E-05
4.0	10	0.175 rads	30.806 deg	0.538 rads	0.00040/nm	0.000120/K	-17.48/rad	5.377/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-4.3E-05	0.00150 deg	5.4 sec	###	1.4E-04	1.6E-04
4.0	12.5	0.218 rads	39.130 deg	0.683 rads	0.00040/nm	0.000120/K	-14.13/rad	4.134/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-3.5E-05	0.00150 deg	5.4 sec	###	1.1E-04	1.3E-04
4.0	15	0.262 rads	47.947 deg	0.837 rads	0.00040/nm	0.000120/K	-11.92/rad	3.267/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.9E-05	0.00150 deg	5.4 sec	###	8.6E-05	1.1E-04
4.0	17.5	0.305 rads	57.461 deg	1.003 rads	0.00040/nm	0.000120/K	-10.39/rad	2.608/rad	0.10 nm	4.0E-05	0.1 K	1.2E-05	0.00014 deg	0.5 sec	#	-2.5E-05	0.00150 deg	5.4 sec	###	6.8E-05	9.5E-05

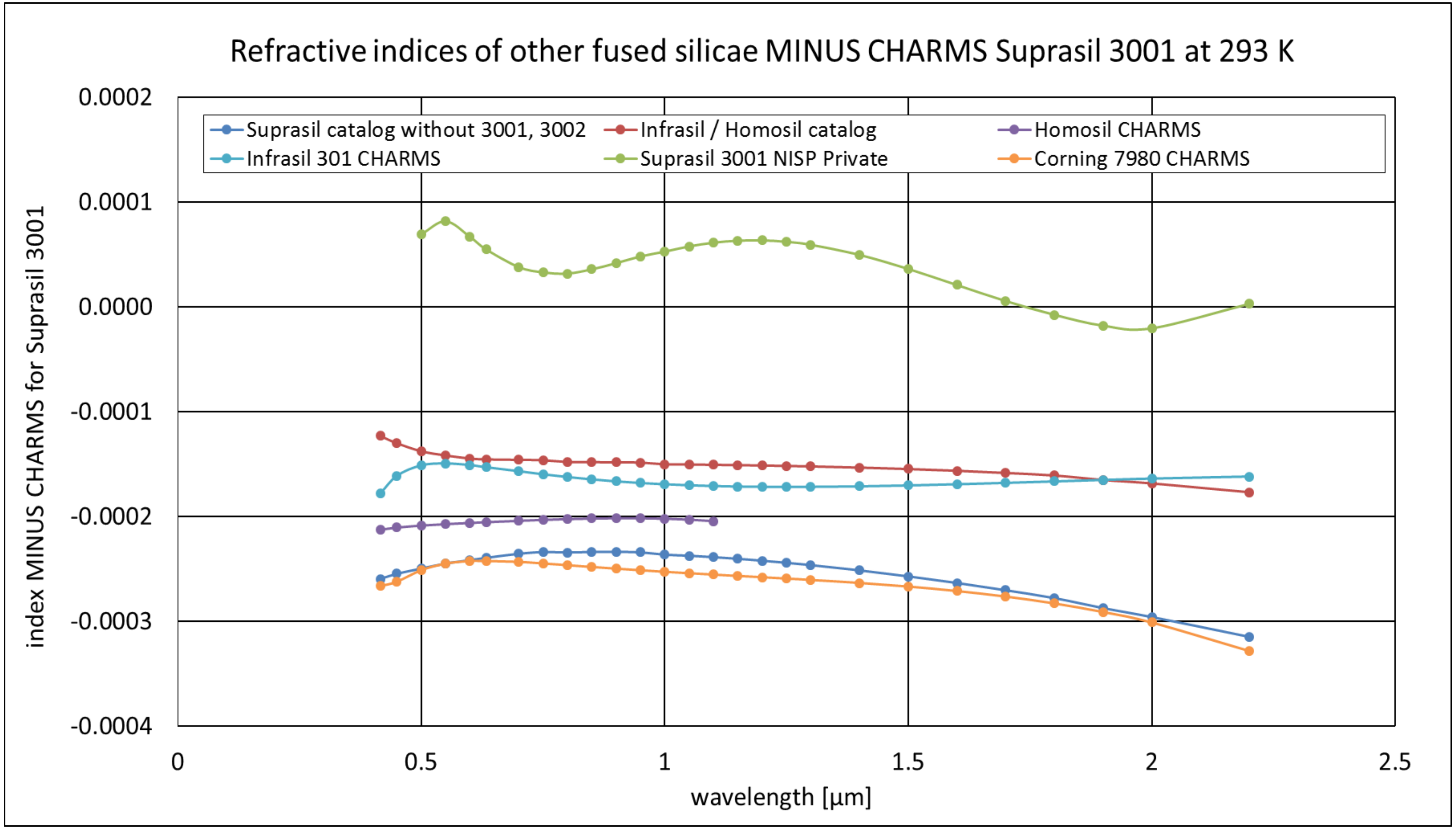
- uncertainty governed by all eight quantities in the red box <u>for each measurement</u> for a given specimen (green box)

so, a refractometer should <u>not</u>
list a single number for accuracy

Measurement Uncertainties



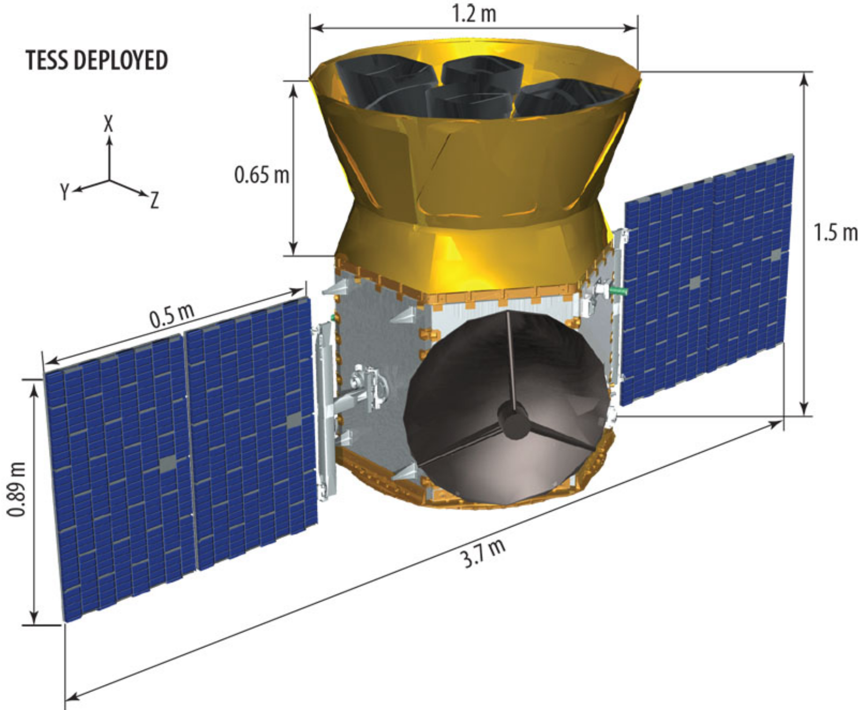
Fused silica is not fused silica is not fused silica …

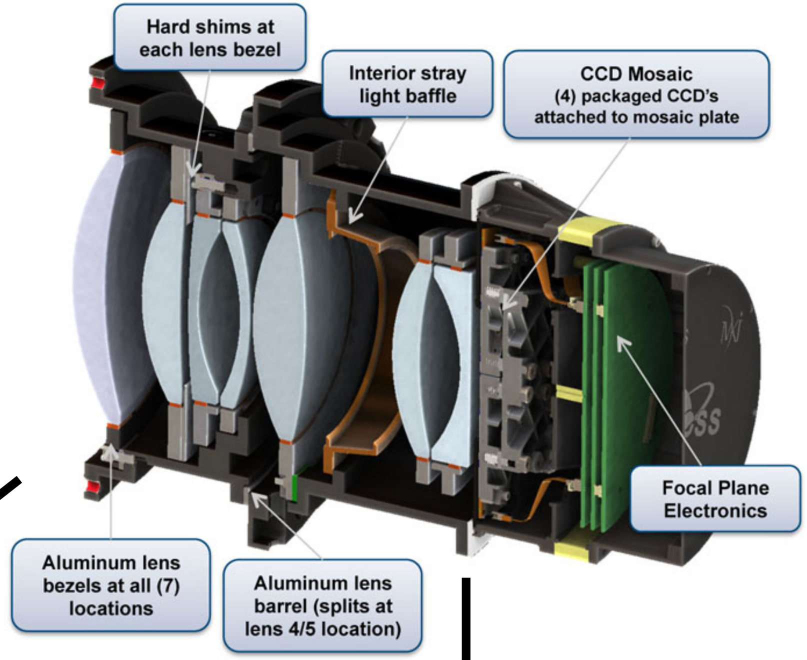


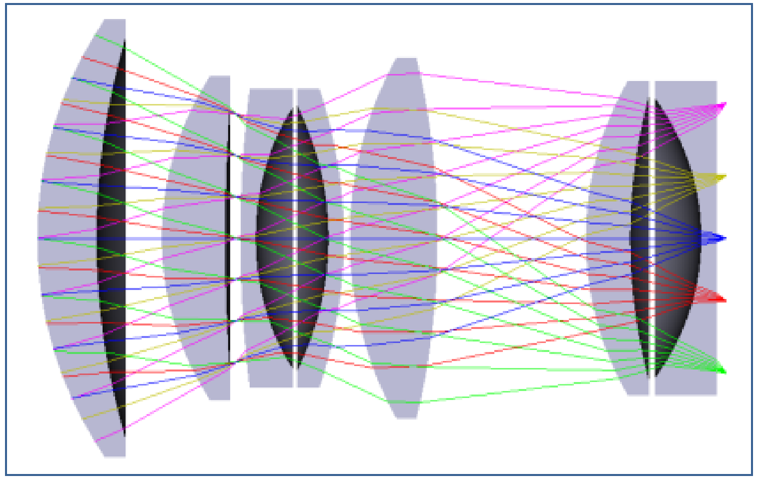
Motivation: Transiting Exoplanet Survey Satellite (TESS)

- Planet finder
- 2017 Launch date (Cape Canaveral, FL)
- 4 identical cameras 90° X 90° FOV
- λ: 0.6 – 1.0 µm; Temp:183—213 K

- **λ: 0.42 – 1.1 µm; Temp:120—300 K**

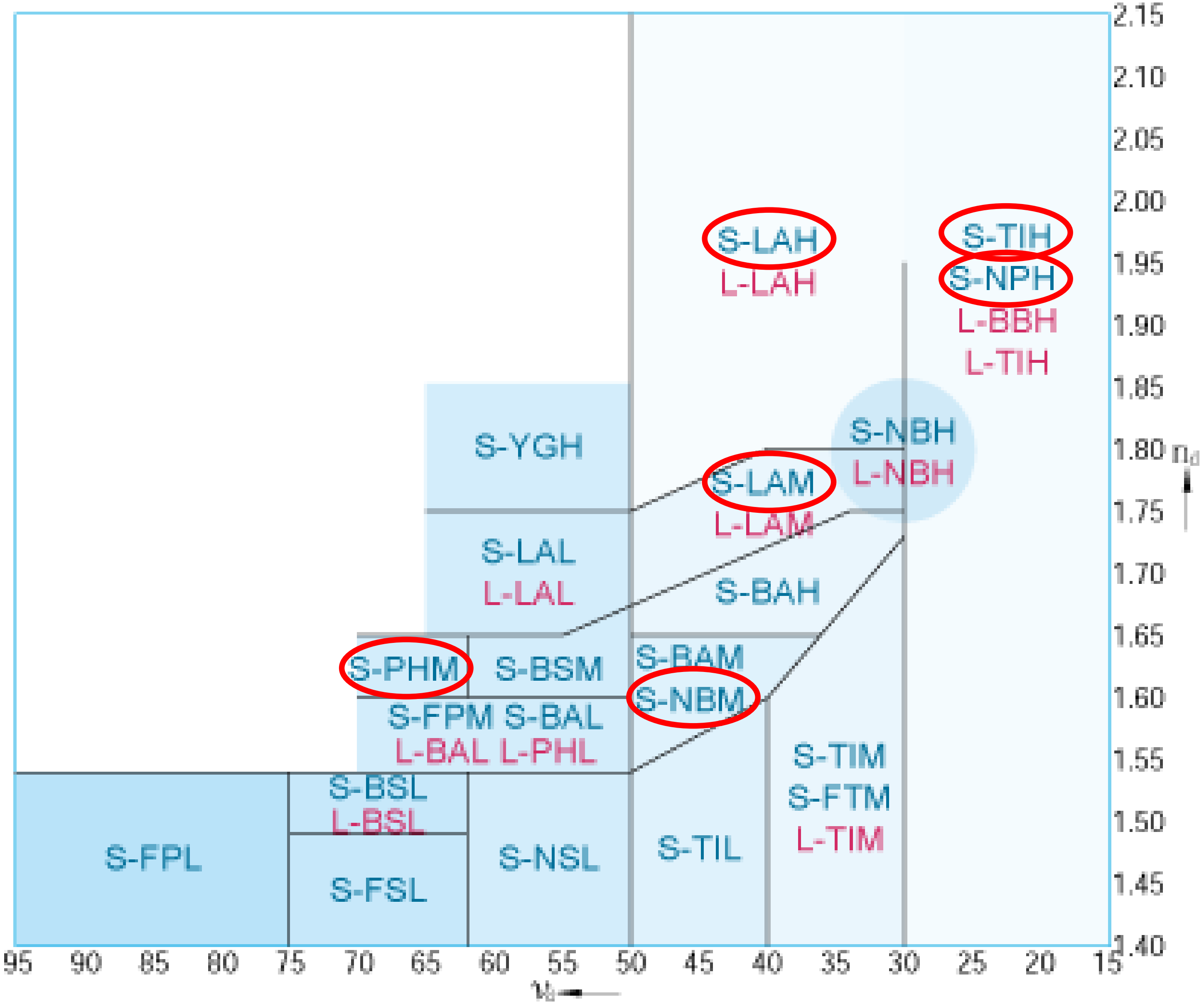






Hybrid Petzval design

Ohara Glasses



Ohara nomenclature example:

Environmentally "safe"

"H" for high index

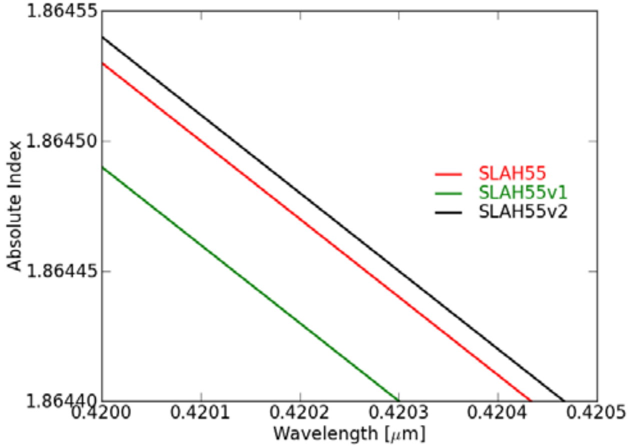
S-LAH59

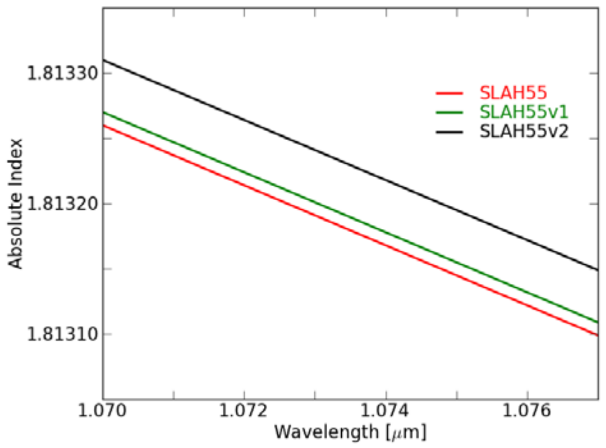
Number of glass within given family

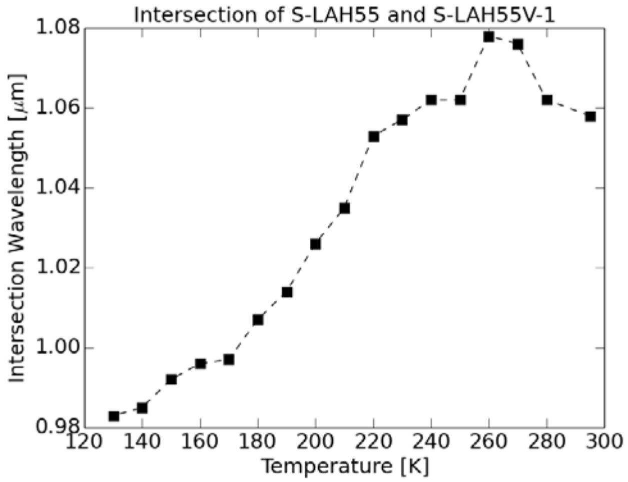
Most important chemical elements contained

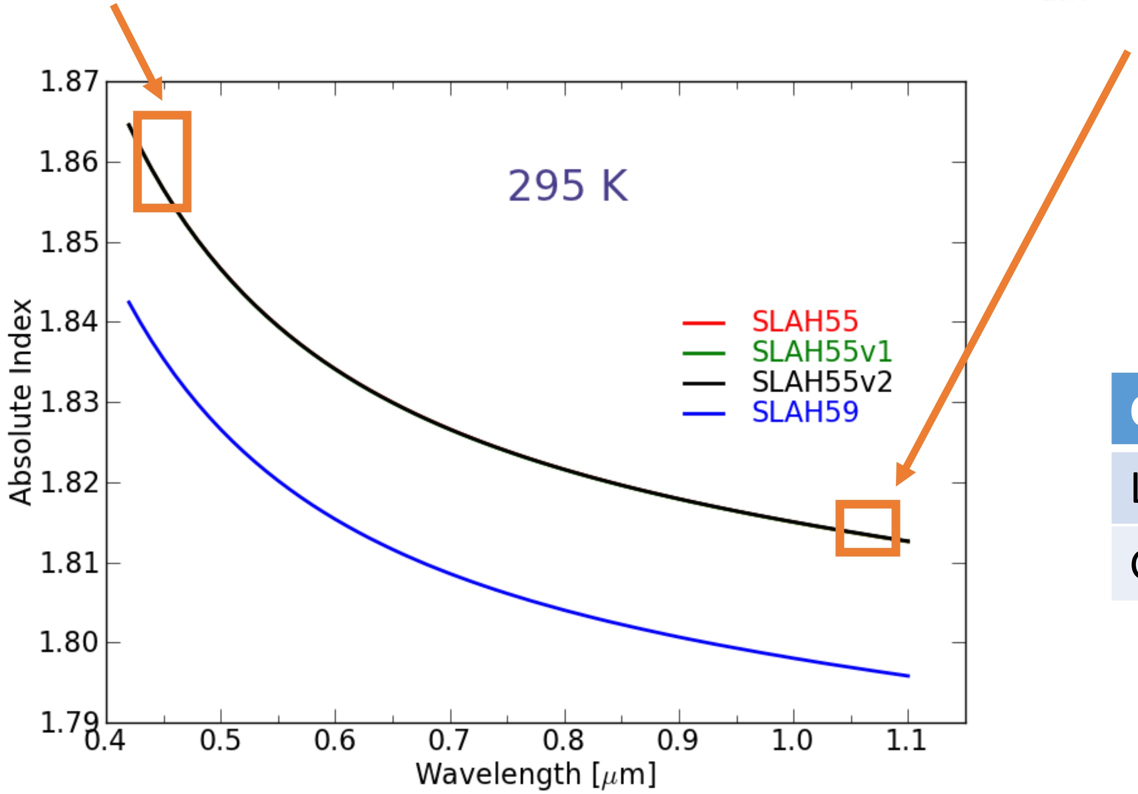
S-LAH55 vs. S-LAH55V

S-LAH55, S-LAH55V, S-LAH59









Constituent % by weight	S-LAH55	S-LAH59
La_2O_3	40-50 %	20-30 %
Gd_2O_3	2-20 %	30-40%

S-LAM3, S-NBM51, S-PHM52

La_2O_3 : 10—20 %

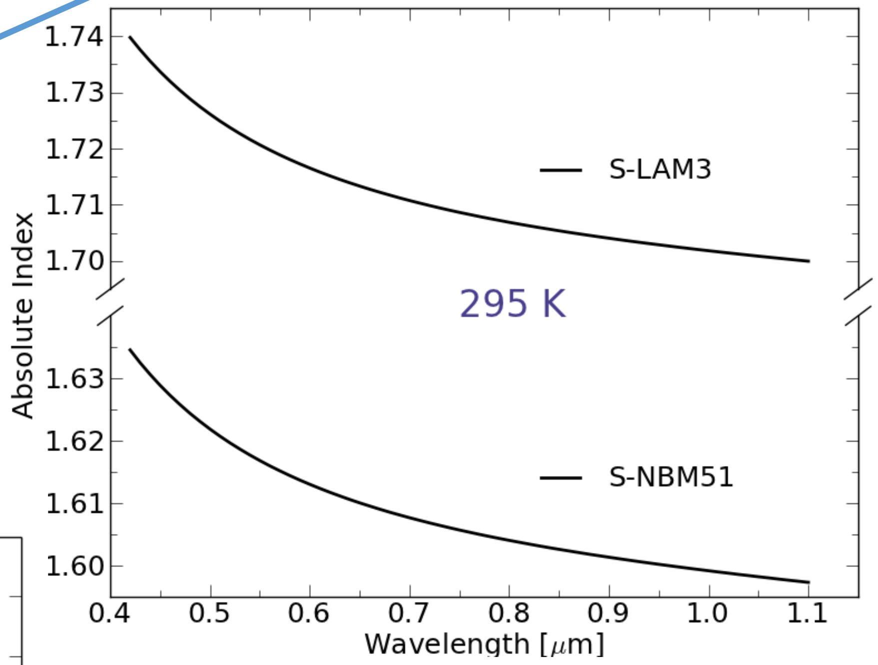
BaO : 40—50 %

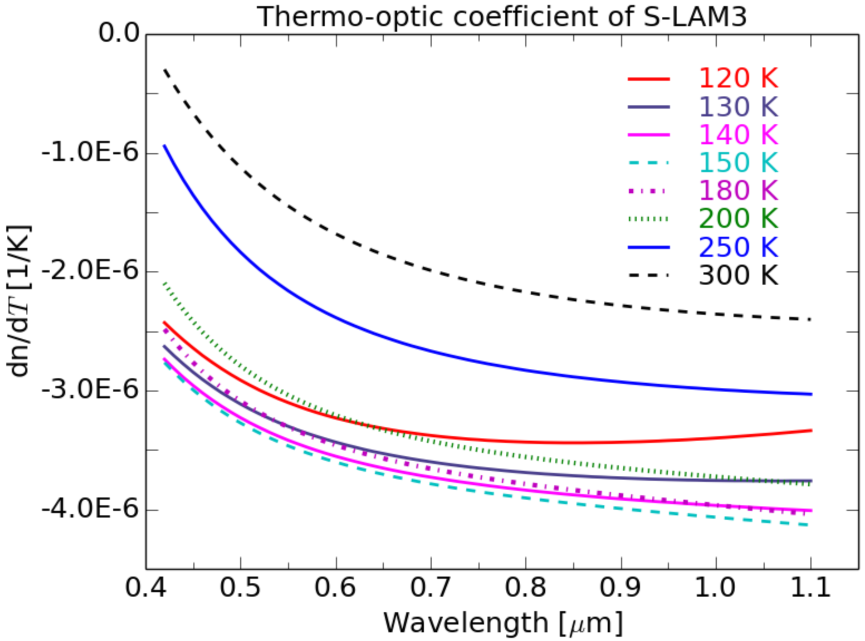
Nb_2O_5 : 10—20 %

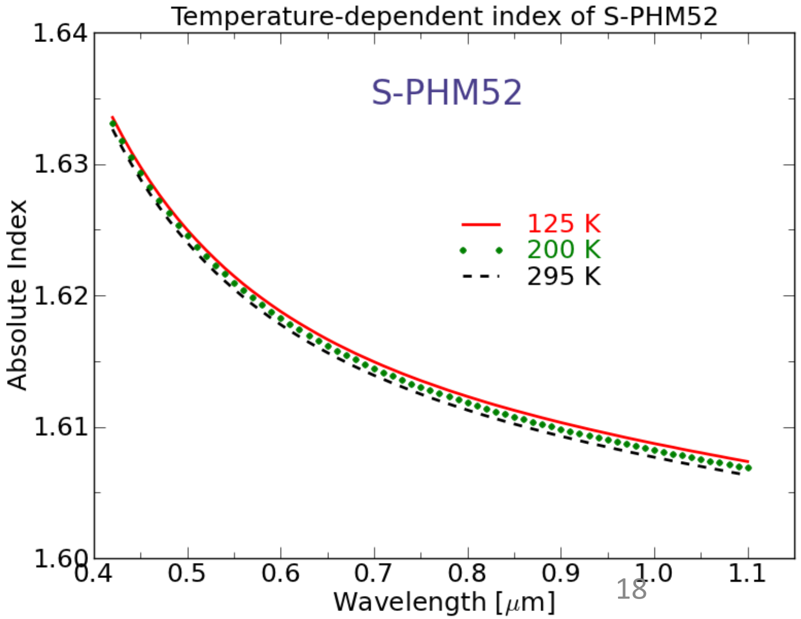
SiO_2 : 30—40 %

P_2O_5 : 40—50 %

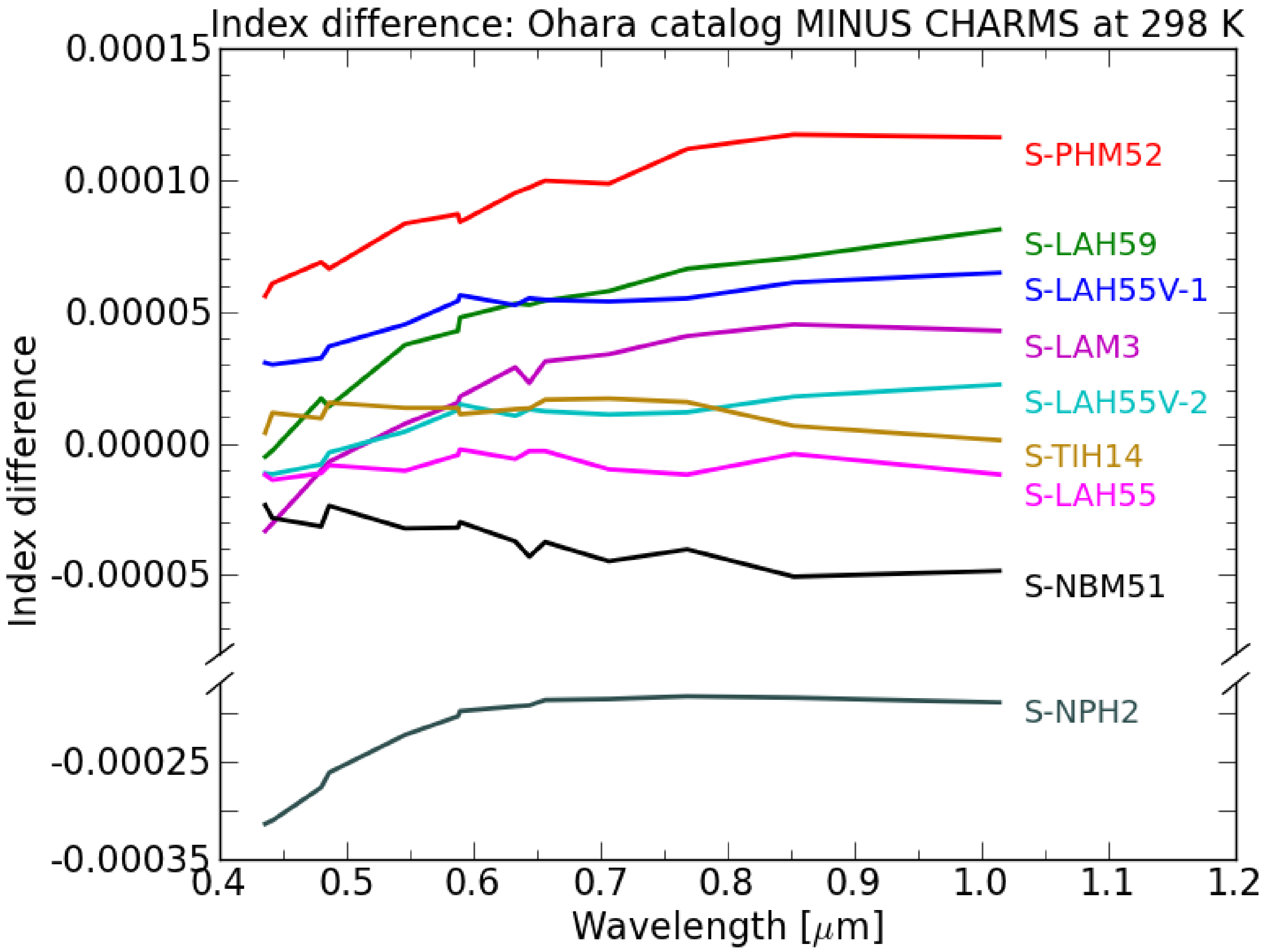
BaO : 30—40 %





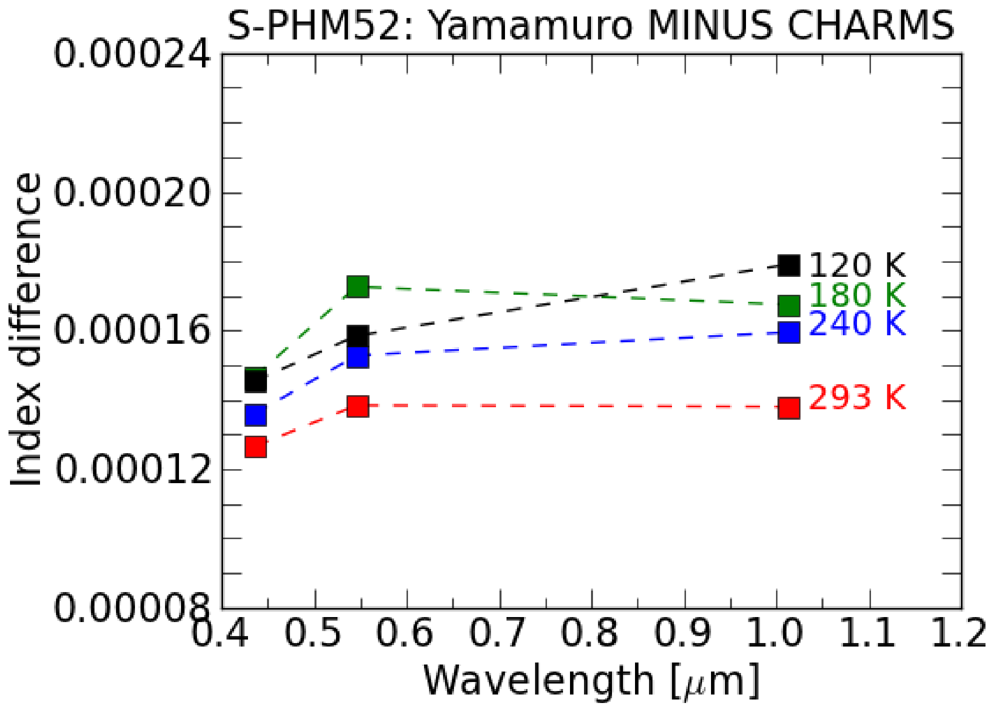


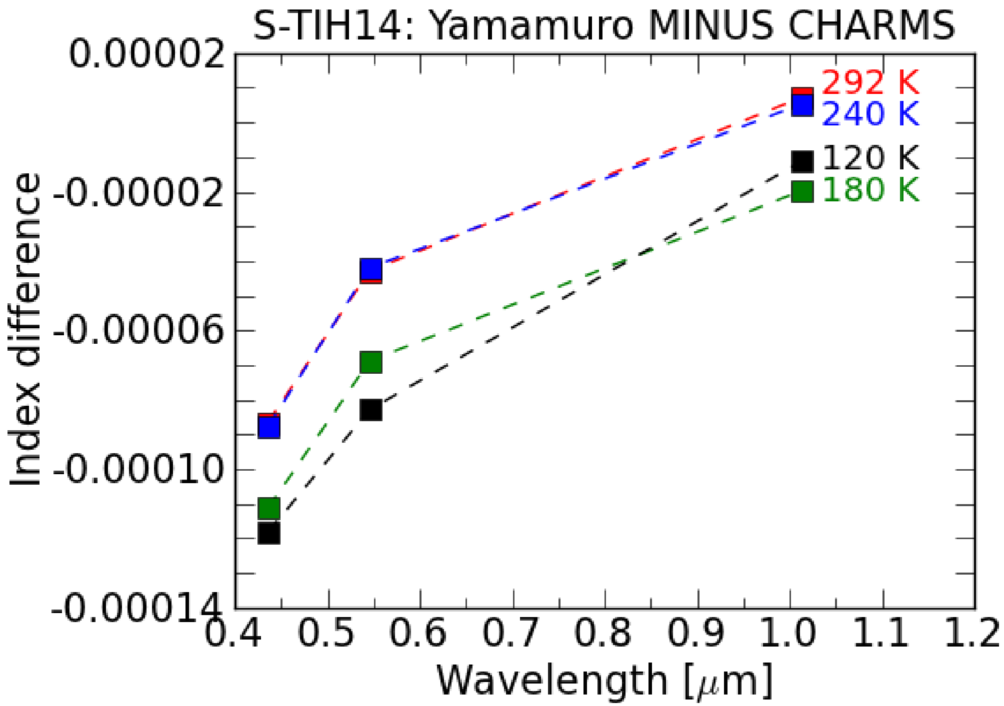
Index Comparison: Ohara MINUS CHARMS



Ohara Optical Glass Catalog, http://Oharacorp.com/

Cryogenic Index Comparison: Yamamuro MINUS CHARMS





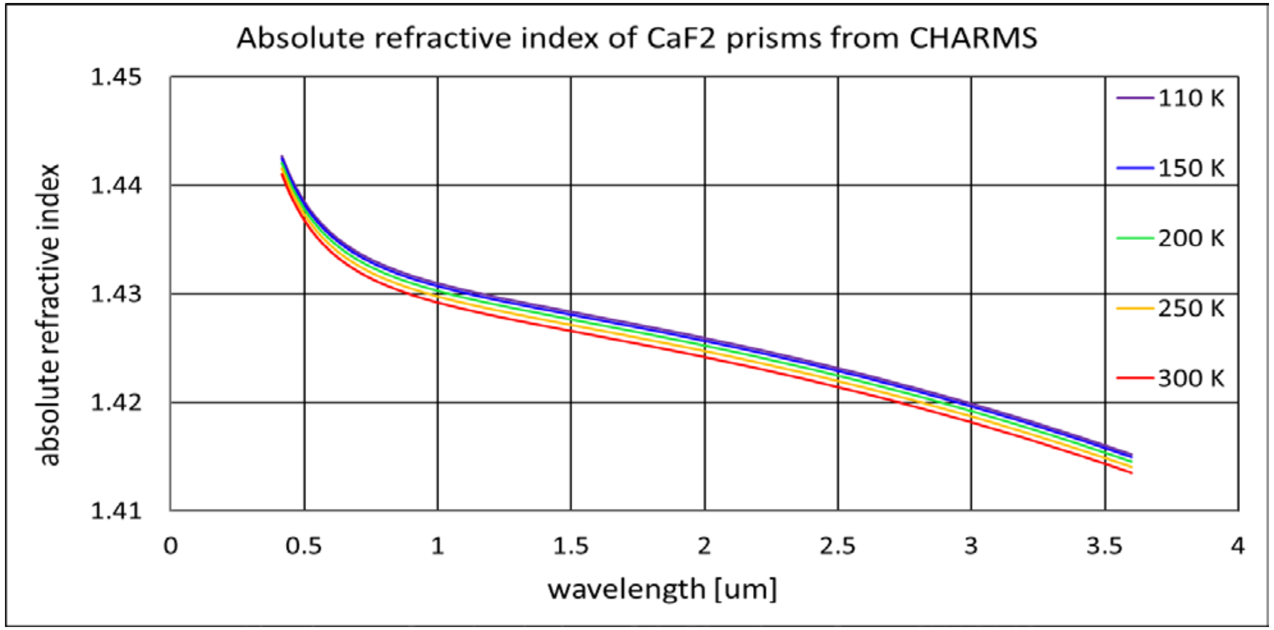
Yamamuro, T. et al., Optical Engineering 45(8), 083401 (2006)

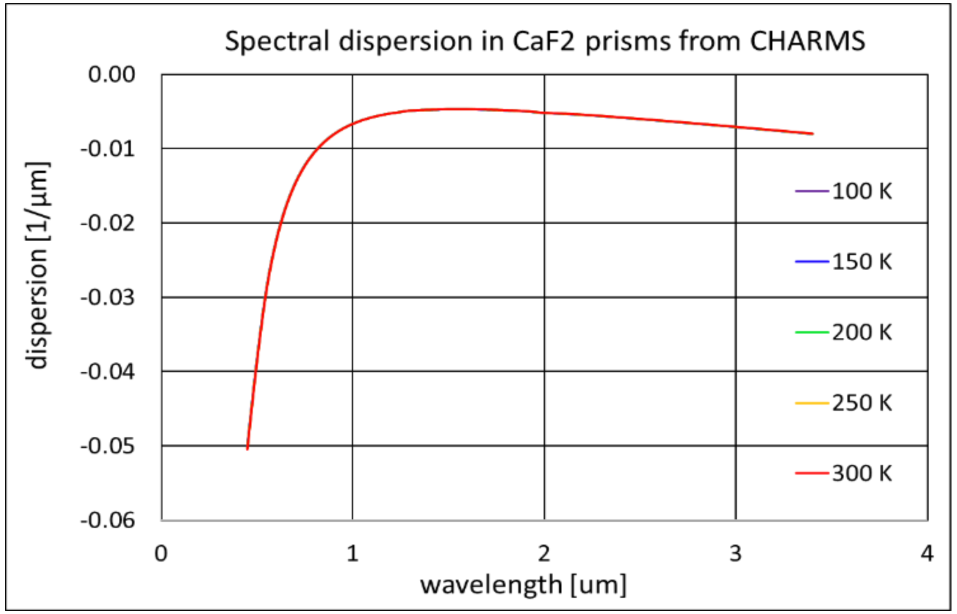
References

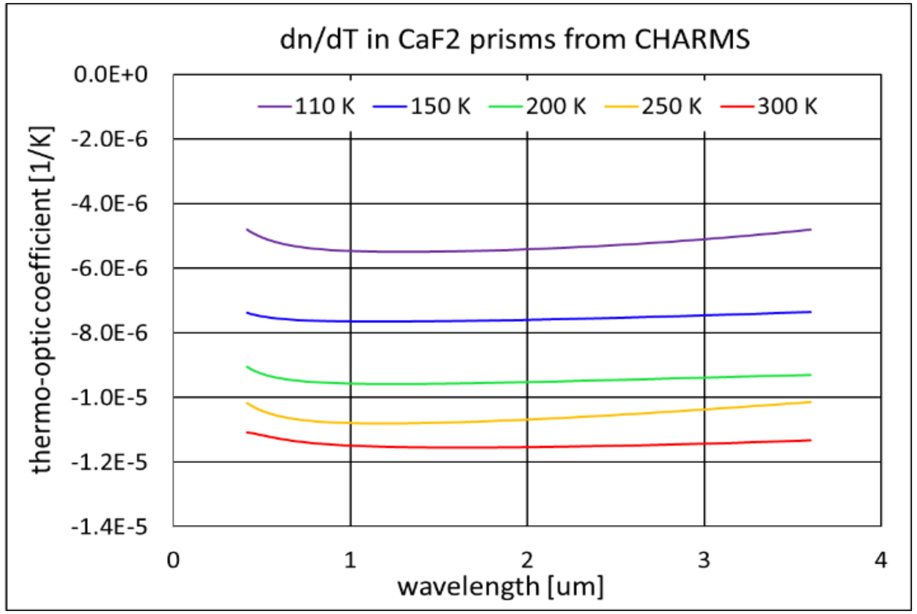
- Miller, K. H., Quijada M. A., Leviton D. B., “Cryogenic refractive indices of S-LAH55, S-LAH55V, S-LAH59, S-LAM3, S-NBM51, S-NPH2, S-PHM52, and S-TIH14 Glasses”, *Proc. SPIE* **9578**, (2015).
- Leviton D. B., Miller K. H., Quijada, M. A., and Groff T. D., "Temperature-dependent refractive index measurements of L-BBH2 glass for the Subaru CHARIS integral field spectrograph ", *Proc. SPIE* **9578**, (2015).
- Leviton D. B., Miller K. H., Quijada, M. A., and Grupp F. U., "Temperature-dependent refractive index measurements of CaF_2, Suprasil 3001, and S-FTM16 for the Euclid near-infrared spectrometer and photometer ", *Proc. SPIE* **9578**, (2015).

Backup

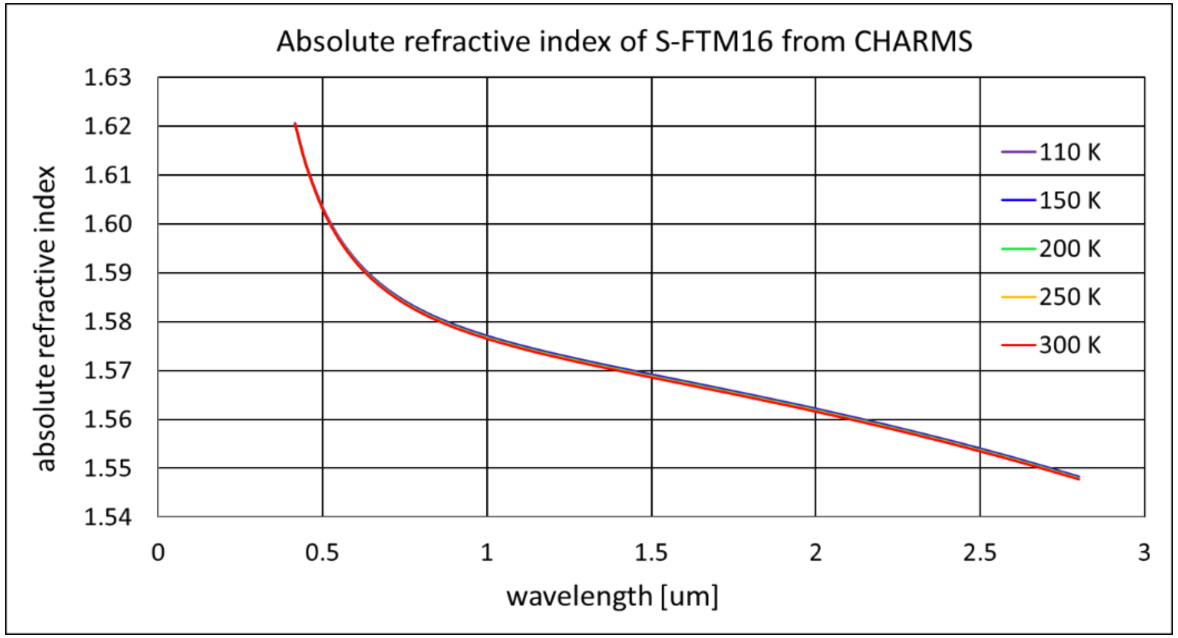
CHARMS measurements of CaF_2 (Euclid)

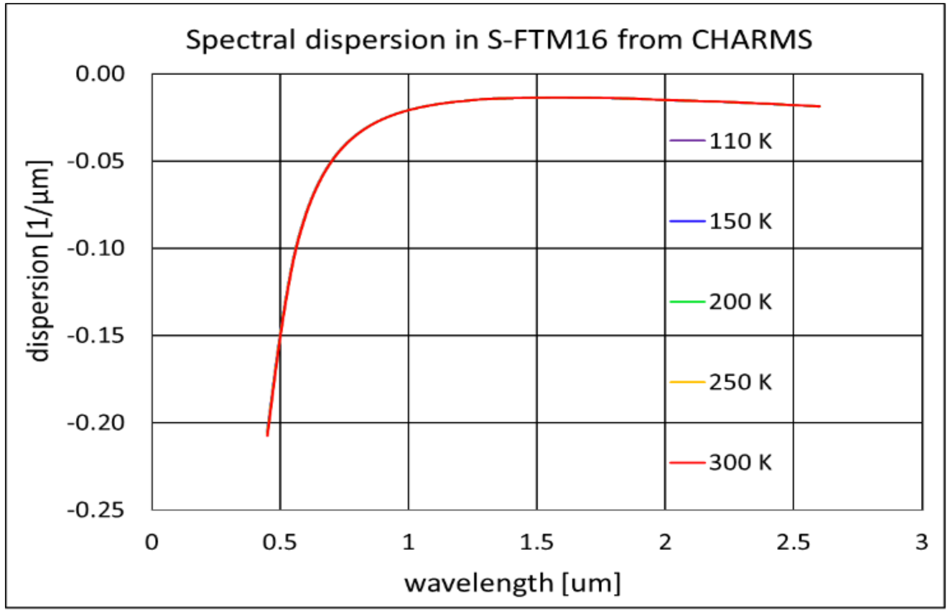


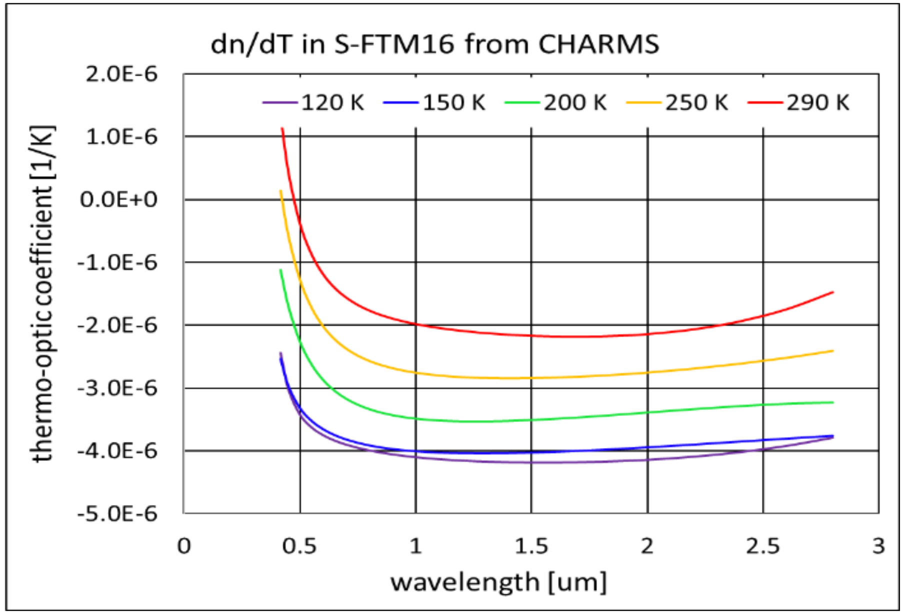




CHARMS measurements of S-FTM16 (Euclid)







CHARMS measurements of Suprasil 3001 (Euclid)